Plug Load Reduction: The Next Big Hurdle for Net Zero Energy Building Design

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ABSTRACT

This paper discusses the importance of reducing plug loads as the industry embraces net zero energy buildings. As buildings have become more energy efficient, plug loads as a proportion of the building load have increased significantly. Data is presented to explain this phenomenon. A methodology and results are discussed for surveys of existing plug loads in an office building and server room similar to many offices around the country, with a view towards reducing energy consumption. Calculations are performed for estimated energy use and potential savings. Finally we discuss developing technologies that can further help to reduce plug load energy use.

Introduction

The age of energy efficient buildings is here. Through tight integration, design teams have been able to reduce lighting and HVAC loads to less than 50% of traditional buildings. As these two largest loads have been reduced, the unregulated "plug loads" in high efficiency Net Zero Energy Buildings have been estimated at around 40% of the remaining building load. Traditionally design teams have considered plug loads to be outside their purview. However, with plug loads evolving into the dominant load of a net zero energy building, design teams clearly must focus on strategies to reduce this critical area of energy consumption.

In a 2006 ACEEE Summer Study paper, Integrated Design Associates, predicted that plug loads could be reduced by 50% in their Net Zero Energy, Zero Carbon building. This team has conducted several subsequent studies analyzing how targeting plug loads can dramatically reduce building energy consumption. These studies exemplify a new model of how a design team can work closely with the end user to minimize plug load energy use. We will discuss strategies for reducing plug loads that we hope will become standard in future Zero Energy Building designs.

In conventional building design practice, a solid line is drawn between the physical building elements and equipment specified by the design team, and portable plug in electrical equipment moved in by the building tenants. This is reinforced by many features of the project delivery process. Contracts define strict boundaries around scope of services. Energy compliance rules and modeling programs separate "regulated" from "unregulated" loads and focusing on the former over the latter. Most fundamentally, architects and engineers follow a libertarian code of conduct in which any whiff of sacrifice, limits on lifestyle or "telling the client how to live" is anathema.

High-performance design practice is moving swiftly towards a true accounting of actual measured energy use in buildings in which a kilowatt-hour saved by an efficient copier is just as important as a kilowatt-hour saved by an efficient chiller. This is driven not only by a heightened concern over building-related climate impacts but the very real cost of renewable energy in Net Zero Energy projects. The Net Zero Energy goal fundamentally alters project economics. No client wants to increase the size of his costly solar array to cover lower cost inefficient equipment. When reductions in plug loads can be quantified and converted into dollars saved in first cost, clients are motivated to commit to purchasing and operational policies up front during the design phases of a project.

The dramatic efficiency gains achieved in integrated design projects are also drawing increased attention to the plug loads. In a typical California office building lights consume around 40% of total energy, HVAC around 25% and plug loads around 15% *[from CEUS data for office buildings of any size in all climate zones in California.]* Integrated design teams today are able to reduce lighting and HVAC loads by 50% or more. Once this occurs, plug loads quickly balloon to 40% or more of the remaining building load and can no longer be ignored. In the IDeAs Office, a net zero energy building, measured plug loads are approximately 45% of the energy use of the building, and are anticipated to grow to over 50% as the HVAC system continues to be fine tuned.

Measured Performance

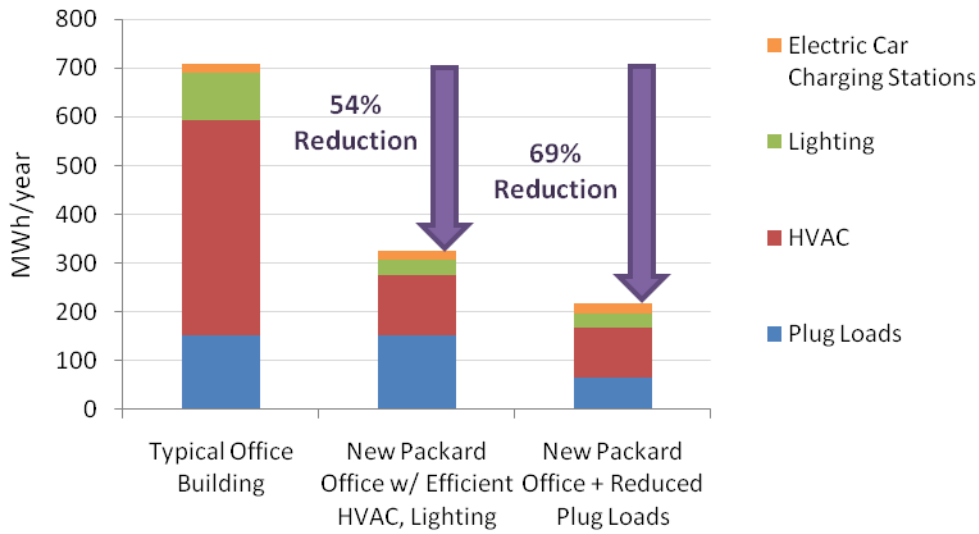
In several recent projects, Rumsey Engineers has completed comprehensive studies of plug loads that show significant energy can be saved in building equipment at relatively low cost. In these projects, we learned that once the client was motivated to analyze plug loads, in some cases getting equipment manufacturers on board with providing lower energy use equipment was not as difficult as originally expected. Also identifying a few surprising areas of wasted energy in efficiency conscious user groups proved to be another important motivator. In other words, many of the barriers to reducing plug load energy use are primarily behavioral, not technical.

We performed several case studies. Two: an office building, and a small server room are notable since there are so many similar types of buildings in the United States. Out of all of these studies energy savings of 44% or more were found to be achievable. Since no one building has the same type of equipment, use schedules, and occupant behavior, we established a formalized methodology for examining building plug loads on a case-by-case basis:

1. Survey existing equipment to predict major energy-users.
2. Interview occupants to predict typical use schedules of equipment and behavior patterns.
3. Provide power monitoring on a selected sample of major energy-users for a substantial period of time.
4. Perform detailed analysis of power monitoring data.
5. Formulate a baseline trend for all equipment based on results of the monitored data to determine design plug loads for each room and for the entire facility.
6. Investigate energy saving alternatives and estimate savings.

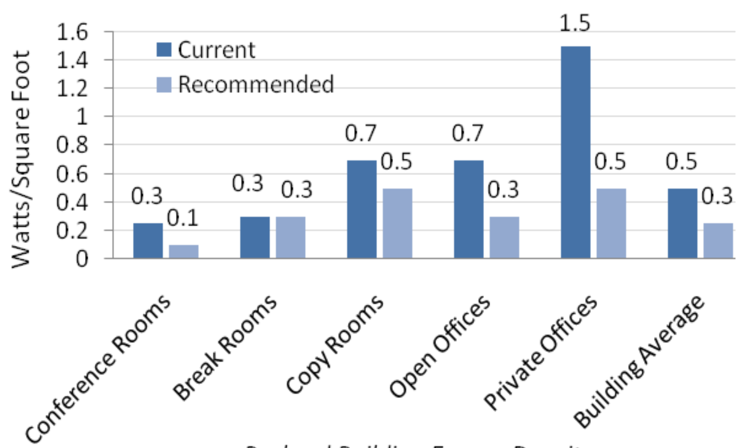
Case Study: Office Building

Rumsey Engineers, with assistance from the staff at the Packard Foundation, measured the power use of a representative selection of equipment at the current 300 Second Street, Packard Foundation office. Also, visual review of equipment at the Packard Foundation's San Antonio office was conducted, including cataloguing of the server room equipment. The measured data was combined with input from the staff and modeled to create an estimate of power use at the new 343 Second Street office – assuming though existing equipment and practices continued unchanged. This profile of energy use of "Current Equipment" became the baseline for the energy reduction recommendations.



Estimated Building Annual Energy Use

The office equipment was first itemized into a list with descriptions of its location and nameplate-rated power consumption. Representative pieces of each type of equipment were then chosen to be measured. Data was then recorded on each piece for a minimum of one day for office equipment and five days for audio/visual and server equipment.

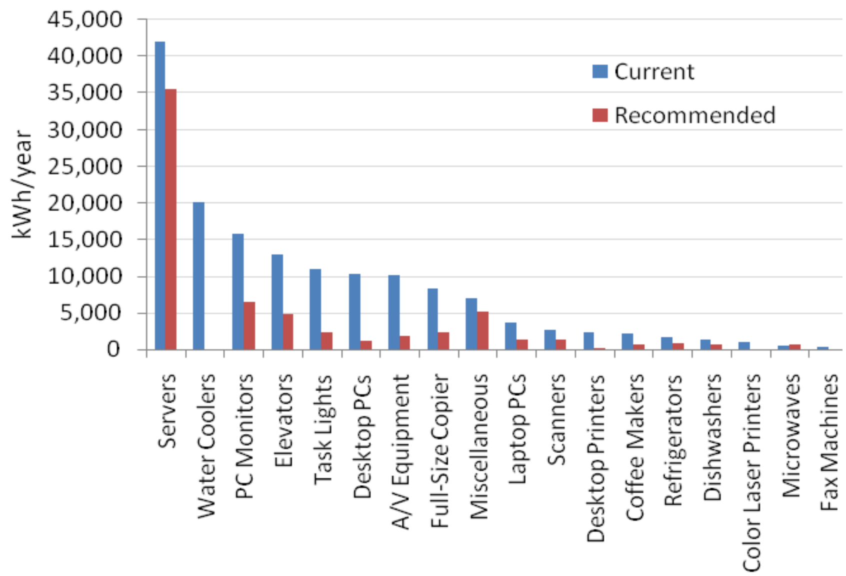


Packard Building Energy Density

Monitoring was accomplished at the electrical panelboards using an integrated data logger and a true RMS power meter, as opposed to simple spot measurements or measurements of amps. Emphasis was put on determining the actual energy usage, as opposed to the rated energy use of the equipment, since there is usually a large discrepancy between the two.

The equipment monitored was chosen such that it would represent the typical usage pattern of that particular piece on a typical day. This data was then extrapolated to provide the baseline model of energy consumption by which all reductions were measured.

By far the most significant energy users in the Packard office were the servers, followed by the water coolers, and the PC monitors. The servers run at a near-steady level of consumption for 24 hours/day, 365 days/year and consume a large amount of electricity. The water coolers depend on energy-intensive boilers and condensers to purify water and are one of the biggest opportunities for energy reductions. The monitors, as well as many other pieces of equipment in the office, do not qualify under the latest Energy Star standards and should eventually be replaced with equipment that does.



Annual Energy Consumption by Plug Load Category

The measures recommended by this study should reduce office plug loads. Reduced plug load will generate less heat and the HVAC system will consequently have less load, further reducing energy consumption. If all recommended measures are put into effect, the Packard office power density being significantly reduced from 0.5 W/sf to 0.3 W/sf. and annual energy consumption will drop from 153,000kWh/year to 65,000kWh/year, a reduction of 58%.

The power currently used by the Packard Foundation is typical of many office buildings today. In addition to saving energy, the recommended reduction in equipment plug loads also saves construction dollars, particularly in the cost of the photovoltaic system that will offset the energy use of the new office building. Empowered by strategies to reduce their equipment plug load power use, the Packard Foundation has the opportunity to become one of the lowest-energy offices in the nation.

Plug Load Reduction Strategies		Current (kWh/yr)	Recommended (kWh/yr)	Reduction
Servers	Use high-efficiency power supplies, high-density servers, and virtualization in the server room.	42,000	35,600	15%
Water Coolers	Replace water coolers with high-efficiency models.	20,100	0	100%
PC Monitors	Replace current monitors with high-efficiency models and attach to power strip occupancy sensors.	15,700	6,400	59%
Elevators	Install Kone EcoSpace elevators.	13,000	4,800	63%
Task Lights	Replace current task lights with high-efficiency LED-based under-cabinet models and attach to power strip occupancy sensors.	10,900	2,300	79%
Desktop PCs	Replace desktop PCs with thin clients.	10,300	1,200	88%
A/V Equipment	Attach A/V equipment to auto-off/manual-on occupancy sensors. Control equipment using a desktop PC.	10,200	1,900	82%
Full-Size Copiers	Purchase two new high-efficiency full-size copiers and attach to timer switches.	8,300	2,200	73%
Miscellaneous	Plug all personal space heaters, fans, cell phone chargers, etc. into power strip occupancy sensors.	7,000	5,200	26 %
Laptop PCs	Replace laptop PCs with high-efficiency models.	3,600	1,400	63%
Scanners	Reprogram touchscreen IKON Docsend devices to turn off at night.	2,700	1,200	53%
Desktop Printers	Reduce quantity of desktop printers from 96 to 12 and replace with high-efficiency inkjet models.	2,300	150	94%
Coffee Makers	Utilize energy-saving modes to reduce or eliminate power consumption when not in use.	2,100	670	68%
Refrigerators	Purchase four high-efficiency models.	1,700	820	52%
Dishwashers	Purchase four high-efficiency models.	1,400	630	55%
Color Printers	Eliminate the use of copy room color laser printers as they are made redundant by full-size copiers.	930	0	100%
Microwaves	Use microwaves as is.	580	580	0%
Fax Machines	Eliminate the use of fax machines as they are made redundant by IKON Docsend devices.	370	0	100%
	Total	**153,300**	**65,000**	**58%**

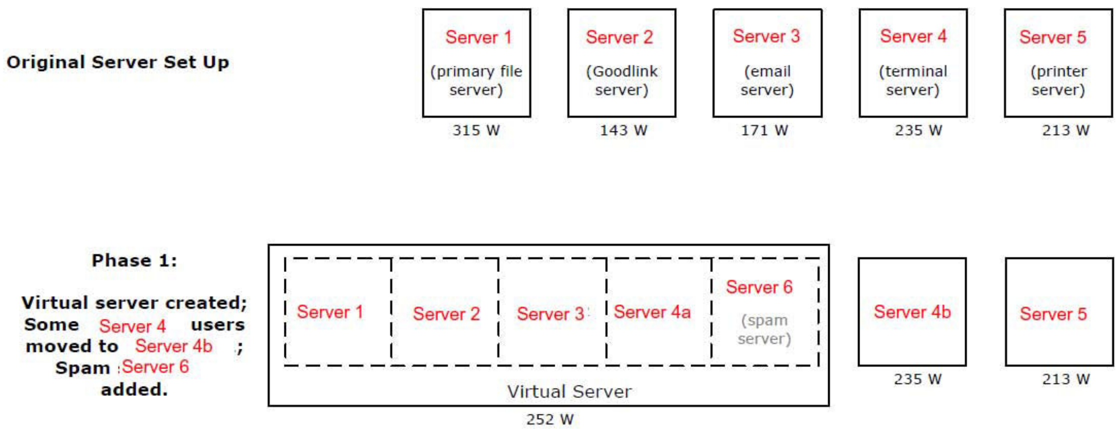
Case Study: Small Server Closet

Another important case study done was the server closet at the office of Rumsey Engineers. Server rooms such as this are common in small offices throughout the country.

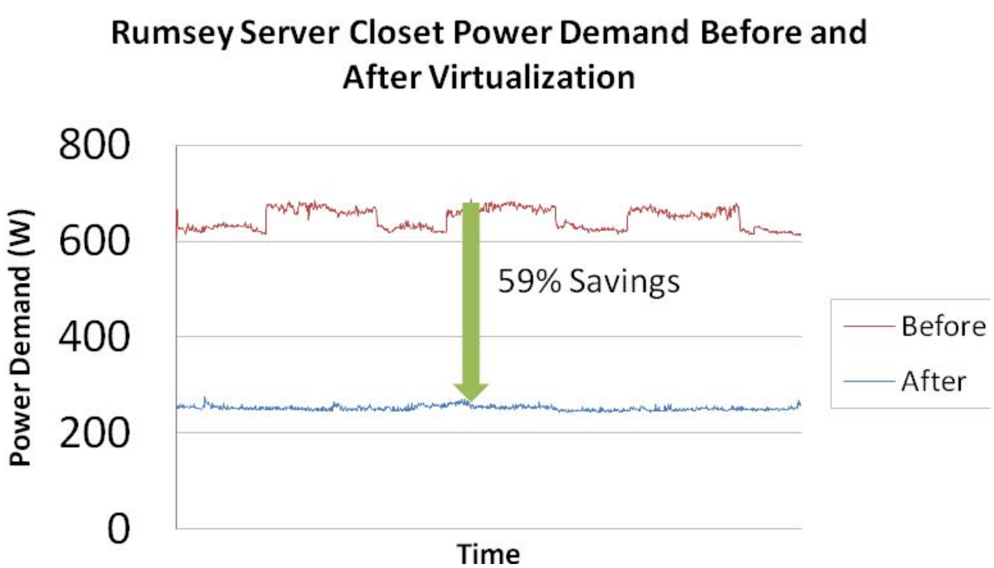
The closet was open to the office and had no dedicated mechanical cooling. With no room to reduce the HVAC energy use, an investigation to reduce server power consumption and losses due to the Uninterrupted Power Supply (UPS) was pursued.

The closet consisted of 5 servers for general office-related applications. After extensive research of emerging server technologies, it was decided that the best way to reduce the power consumed by these servers was through virtualization. Typically servers do not work at their full capacity, only running one application at a time. Virtualization of servers is a technology that maximizes server capacity by hosting several applications on one virtual machine that would typically be running on multiple machines.

One limitation with virtualization is that it is not compatible with all types of servers. It is compatible with most typical office applications such as email and file sharing, however. For highly scientific computational processes, virtualization is not recommended. Assessment of the Rumsey Engineers servers discovered that three out of the five servers were capable of virtualization:



The power consumption of all servers was monitored for one week on five minute intervals before and after virtualization. For the three servers that were consolidated, Server 1, Server 2, Server 3, the average power draw was reduced from 629 W to 252 W, which resulted in an overall annual reduction of 33,000 kWh.



Standby Loads: To date most of the efforts related to energy efficiency for plug loads have been focused on developing or specifying equipment that is more efficient in active use. However, similar to energy efficiency in lighting, a tremendous amount of energy savings is available from simply turning off appliances when not in use. In the computer industry, software used to automatically put personal computers, screens and printers into standby or "sleep" mode when inactive has become the standard. As mentioned previously server software is available capable of reducing energy use when servers are fully utilized.

One key difference between light fixtures and plug in appliances is that many appliances have a "standby" mode where they continue to use energy even when the appliance appears to be off. This is a well documented phenomenon known as "phantom loads".

In some cases, the energy consumed in this "standby" mode can be significant; hence the growing concern with phantom loads. An example of a common piece of equipment with high phantom loads is a conventional CRT type television screen. Although a television appears to be turned off, in actual fact the equipment is continually seeking a signal from an associated remote control to start up. Measurement of the actual energy use of a traditional 36 inch CRT television in operation varied between about 161 to 188 watts, averaging about 180 watts. When turned off, the same screen drew about 12 watts in standby mode. If this television is used 4 hours a day (the US average) **(NationMaster.com),** it would use about 720 watt hours of energy per day in active use and an additional 240 watt hours or 1/3 of the active energy use in standby.

In equipment with low hours of use, energy consumed in standby can exceed energy consumed during active use. For example during the course of a day, a microwave oven can use more power in standby, running its clock than actually cooking even though cooking uses as much as 100 times the power required to running the clock.

In an ACEEE study published in 2000 by Benoit Lebot et. al., standby power loads around the world were estimated to account for between 3 and 13% of household power consumption. **(Lebot)**

Measured standby loads for various pieces of common electrical equipment vary from 1 to 2 watts for battery chargers (when not in use) to over 35 watts for cable boxes, **(Freeman)** and an astounding 120 watts for a first generation TiVo (which arguably does not have a standby mode).

However as awareness of the need for energy efficiency increases, phantom loads have come under increased scrutiny and innovative new equipment with higher energy efficiency in standby mode is gradually becoming available. An example is the new high efficiency, Samsung, 55 inch flat screen LED TV whose standby load was so low that it measured at 0 watts on a watt meter.

Three Promising New Technologies

We believe that there are three additional areas of technology developing that could support continued plug load energy efficiency improvements. These are: improved plug load controls, DC microgrids and detailed monitoring.

Plug Load Controls

There are several promising products and ideas for controlling power outlets that are gaining acceptance and popularity.

Occupancy sensor controlled plug strip. The first is occupancy sensor based controls of actual plug strip type power outlets to automatically shut off the power when no user is present. One example of this is the WattStopper Isolé.

The Isolé is an 8 receptacle surge suppressor, plug strip that incorporates a passive infrared occupancy sensor to switch off outlets. The occupancy sensor has a user adjustable time delay from 30 seconds to 30 minutes and controls 6 of the 8 outlets on the plug strip leaving two unswitched for loads that users do not want automatically turned off.

A typical application for the product is to mount the occupancy sensor in an office cubicle on the underside of a desk, (shielded from view of the adjacent aisle to avoid false tripping). The user's computer is plugged into one of the unswitched outlets and peripherals that do not need to stay on when the cubicle is unused such as the computer screen, speakers, printer, task lighting, or personal fans are then plugged into the switched outlets. If the user walks away from his cubicle, after a preset time out period, all of the items plugged into the switched outlets will be shut off, eliminating and active or standby loads from the associated equipment. **(WattStopper)**

Occupancy sensor controlled outlet. A similar occupancy sensor controlling a single power outlet that automatically shuts off the power when no user is present is named the SensorPlug available from Andev. It contains a single power outlet, is rated for 500 watts and uses 36 watts in standby. **(SensorPlug)**

Occupancy sensor circuits. Another permutation of this concept is to use the same occupancy sensors used for lighting control to also control receptacle outlets. The new WattStopper DLM system which employs an innovative, modular "plug in" control system consisting of standard Category 5e cabling, allows the connection of a network of occupancy sensors, daylight sensors, EMS interfaces and a computer to monitor and control both light fixtures and receptacles. Using this system, circuits supplying wall receptacles can be programmed to shut off power using room occupancy sensors just as lights controlled.

Power sensing plug strip. A different take on the surge suppressor, plug strip idea is the APC - P7GT "power-saving surge protector". The P7GT is a 7 outlet, surge protector, plug strip that contains a master control outlet with three slave outlets and three additional unswitched outlets. When the master control outlet detects that power use has fallen significantly (i.e. the computer plugged into the master control outlet is switched off or goes into sleep mode), the three switched outlets automatically shut off.

A typical application for this product is to plug a cable TV box into the master control outlet and peripherals such as the TV, AV Receiver, DVD Player, etc into the switched outlets. When the cable box is turned off, the power-saving surge protector automatically shuts off power to all of the other devices eliminating phantom load losses from those devices. **(American Power Conversion Corp.)** A similar device is available from BITS Limited. **(BITS Limited)**

Security System Shutdown: In the net zero energy, zero carbon emission IDeAs headquarters office, the Security System was used as a proxy to detect when the building was unoccupied to shut down printers. Since laser printers have a relatively long boot-up time, it was impractical to turn off printers during the day, when they were in standby mode waiting to accept print requests. However, the standby energy use of these types of printers is significant, ranging from 5 watts for a laser printer to 30 watts for a laser plotter. When the building is unoccupied, there is no reason to leave the printers on. IDeAs decided it was unrealistic to expect the last employee out to consistently remember to shut off the printers on their way out, so the solution was to have the security system programmed to automatically signal remote controlled circuit breakers to shut down the power supply to the printer circuits when the system was armed.

DC Microgrids

Installing DC microgrids is another interesting new concept that provides the promise of greater energy efficiency for supplying power to plug in devices. The EMerge Alliance is a consortium that is working on developing standards and products for DC microgrids. The premise is that much of today's plug in and wireless electronic equipment runs on DC power, and for buildings that have photovoltaic or other DC on site power generation systems, it is more efficient to directly use the DC power rather than convert it to AC for distribution throughout the building and then later convert it back to DC for use in individual pieces of equipment.

Personal computers and laptop computers run on DC power as well as cell phone chargers, electronically ballasted fluorescent lights, LED and halogen desk lamps. Nextek power claims savings of over 10% to 40% through bypassing the multiple conversions required between DC and AC systems.

An example of how this might work is in a typical office where the majority of plug in equipment including items such as PC's, LED task lamps, cell phone chargers, and speakers run on DC power. During daylight hours this equipment could run on DC power taken directly off of a photovoltaic system and run through a high efficiency DC to DC converter with losses of just 2 or 3 percent as opposed to 20 to 30 percent when converted to DC and then later back to AC. At night, an AC to DC converter can make the DC power at higher efficiency for the circuit than is economical to do at every device. For buildings incorporating large (say 30% of total power production or more) photovoltaic arrays, this system could potentially provide the majority of the power for DC powered plug in equipment during working hours. This is because in a standard office building, daylight hours closely match working hours where plug in equipment is primarily used during the vast majority of the year. An added benefit is that during power outages it would be possible to continue to provide power to DC equipment if adequate sunlight is available.

Detailed Monitoring

Although monitoring does not directly save energy, it plays two very important roles in saving energy. First in providing data to help users to understand where, when and how much energy is being used. Second providing direct feedback to individual users on energy consumption generally has the effect of encouraging them to reduce their energy consumption.

Data collection. Using monitoring equipment provides valuable data on the usage patterns and amounts of energy that is used by plug in devices. This can help researchers to better design systems and determine what types of innovations will be most helpful in reducing plug load energy use.

An example of how this can be done is the new WattStopper DLM system which is an innovative new modular control system using standard Category 5e cabling to connect a network of occupancy sensors, daylight sensors, EMS interfaces and computer monitor to control light fixtures and receptacles. This system also monitors energy use at the device level.

Feedback for behavioral change. We believe that one poorly understood and documented factor in reducing energy use in buildings is the role that building users play in reducing their own energy consumption. This is especially true in regards to plug loads, where much of the consumption is controlled by individuals using personal devices and their unique actions. In addition, it appears that providing simple easy to understand feedback to users on their individual energy use can affect behavior and improve energy savings as users become aware of their personal energy use and how their individual actions affect it and modify their behavior to use energy more efficiently.

Examples of similar technologies that are being developed in this area include Adura, a wireless lighting controls manufacturer that has developed a product which provides wireless manual, occupancy and daylight based controls combined with simple internet accessible energy monitoring output to monitor energy use and allow users to see how much energy they are consuming. This could easily be adapted to provide monitoring and control of plug loads as well. Another firm, Infosys, an Indian based IT consulting company is developing an in house wireless monitoring system that measures how much energy employees use in their individual cubicles, and provide feedback on their paychecks!

Conclusion — What are the Potential Savings?

As the building industry moves aggressively towards making net zero energy buildings standard design, a new challenge for building designers is making plug loads and equipment selection part of the basic building design and educating tenants and owners on the importance of their plug in appliance purchases. As designers, manufacturers, owners and consumers all come to understand the "plug load" issue and the role of plug in equipment in minimizing energy use, we believe that this area of research will continue to gain importance and become one of the next key areas for saving energy and reducing carbon emissions. An added advantage of focusing on reducing plug loads is that many of these same concepts can be adopted in existing buildings that are not currently being redesigned as high efficiency energy increasing the potential rate of energy savings available.

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